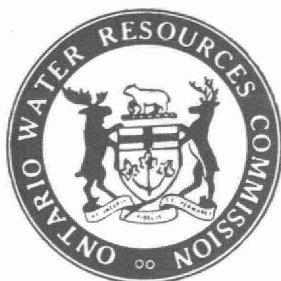Research paper 2007

HYDRAULIC CHARACTERISTICS

OF

COMMON WATER FILTER MEDIA

DIVISION OF RESEARCH

ONTARIO WATER RESOURCES COMMISSION

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HYDRAULIC CHARACTERISTICS

OF

COMMON WATER FILTER MEDIA

By

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INTRODUCTION

This paper is designed to provide basic hydraulic data pertaining to filter media commonly used in water treatment filters. For this purpose the following materials were selected for evaluation:

1) "Ottawa" sand

2) Anthracite coal - "Anthrafilt" #1-1/2

3) Anthracite coal - "Anthrafilt" #2

The data obtained are applicable to the design of both conventional rapid sand filters and multi-media filters in that initial and relative head-loss may be determined.

EQUIPMENT AND PROCEDURE

A filter column as shown in Figure 1 was
constructed in the laboratory. The column consisted of an
acrylic tube, 155 cm long with a 10.8 cm inside diameter, open
at the top and closed with a gasketted, slide-fit cap at the
bottom. The cap, with central 13 mm pipe outlet, supported
a layer of 15 mm diameter glass beads upon which a 595 micron
screen was supported. The filter media was placed directly
on this screen. Manometer taps were inserted into the column
immediately above the screen (to eliminate effects of system
head loss) and at 20 cm vertical intervals above the screen.
These taps were connected to a multi-bank manometer.
Influent, consisting of tap water, was provided through
rubber tubing connected to the laboratory potable water supply
with free discharge to the top of the filter column. Effluent
was discharged through the bottom pipe and flexible tubing
to a flow meter (Fisher and Porter 1027 "Flowrator") and from
there to waste. A control valve on the discharge line regulated
the flow. Backwash was accomplished by connecting the dis-
charge pipe to the potable water supply with backwash waste-
water discharged through a syphon (with aspirator assist) at
the top of the column. The entire assembly was supported on
a free-standing angle iron frame.

Inlet

Backwash

10.8 cm D
Col.

Manometer

Flowmeter

Outlet

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SCHEMATIC DIAGRAM
of
FILTER   COLUMN

fig 1   nts
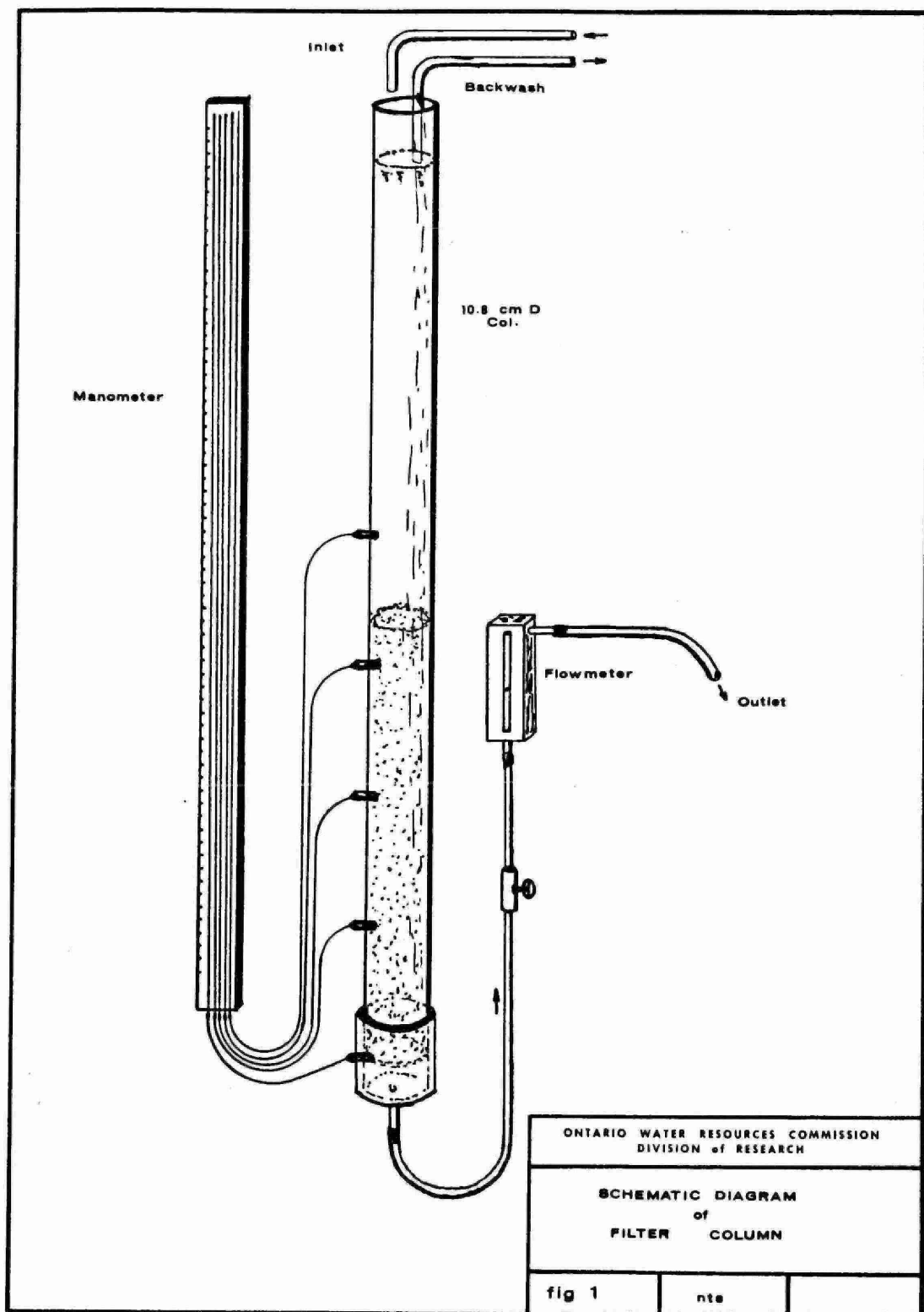
The test procedure used for each type of media was similar. An amount of raw media was added to the column to give a workable filter depth and backwashed at a rate, and for a time, adequate to remove all dirt particles and extremely fine material. The backwash was shut off, the media allowed to settle, and the feed started. After the bed had stabilized the depth was measured. Flow rate was varied over the test range and bed head-loss measured at each flow rate increment. Each test run was duplicated by starting at a low flow rate, increasing in increments to the maximum rate and then decreasing by the same increments back to the starting rate. Throughout the test the influent water temperature was maintained at $10°C \pm 1°$. After each test the filter was backwashed and the procedure repeated. At the conclusion of a test series the media was recovered, air-dried to a surface dry condition and weighed. A representative sample was submitted to a sieve analysis and the porosity of the material obtained by the displacement principle. (Sample calculations are included in Appendix A)

TEST RESULTS

The results of the sieve analyses for the three media tested are shown in Figure 2. Analyses were done using the International (ISO) Standard sieve series plus intermediate sieves to provide additional values where required. Table 1 presents a summary of these results.

TABLE 1

	df	UC
Ottawa Sand	0.55 mm	1.49
Anthrafilt #1-1/2	0.95 mm	1.84
Anthrafilt #2	1.70 mm	1.77

Results of the head-loss tests for the three filter media are shown in Figure 3. It will be noted that more than one value of porosity (f)* is shown for each filter material. The values shown are those obtained when the material settled after backwash and represent the variations in porosity which may occur in actual practice. The effects of the variation in f are significant at high flow rates.

*porosity - f - is defined as the ratio of the void volume to the total volume of material including solids and voids.

U.S. BUREAU OF SOILS CLASSIFICATION
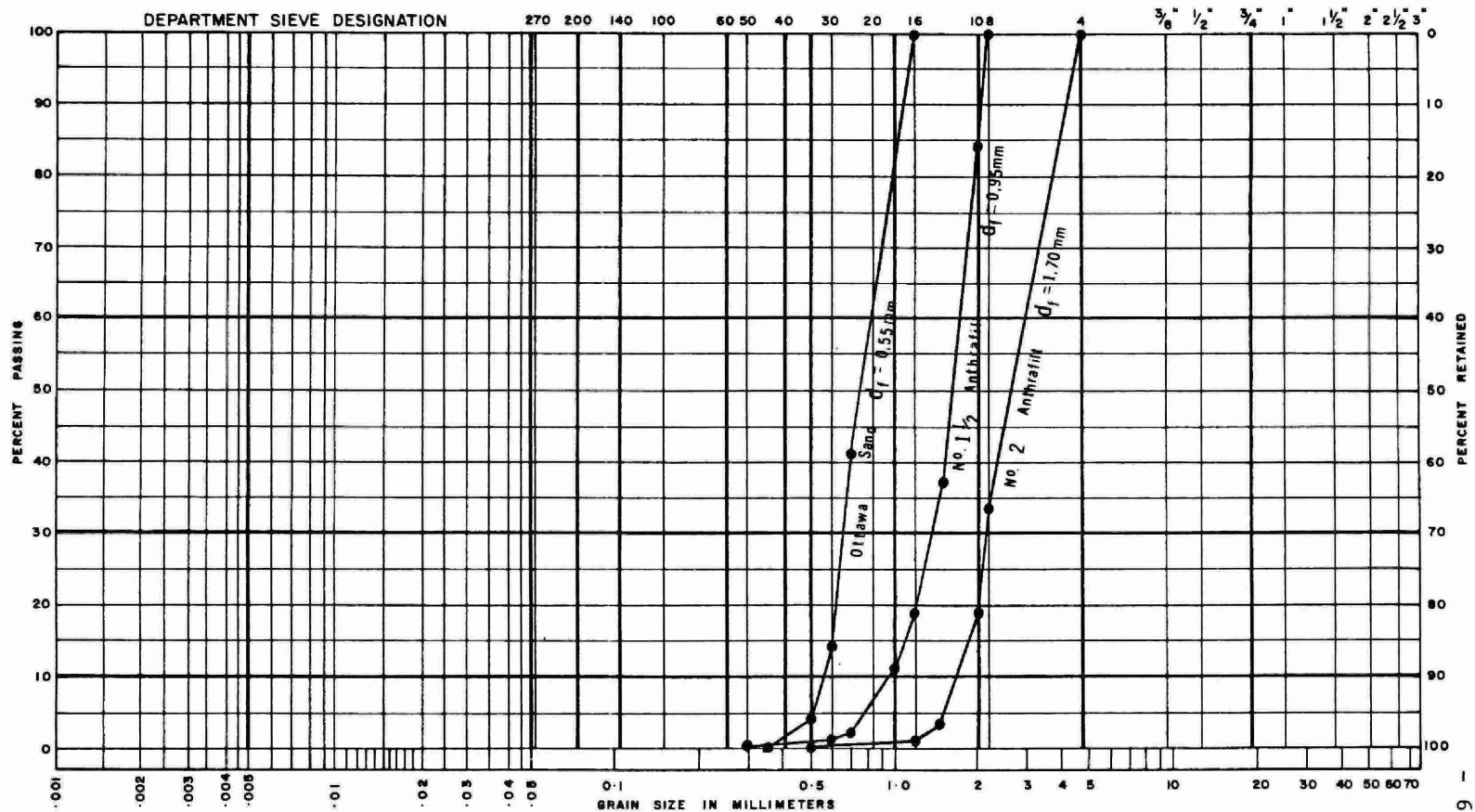
UNIFIED SOIL CLASSIFICATION SYSTEM

REMARKS _____ FILTER MEDIA SIEVE ANALYSES _____
_____ - Samples graded after backwashing _____

DATE ___ March 1967 _____ Fig. 2
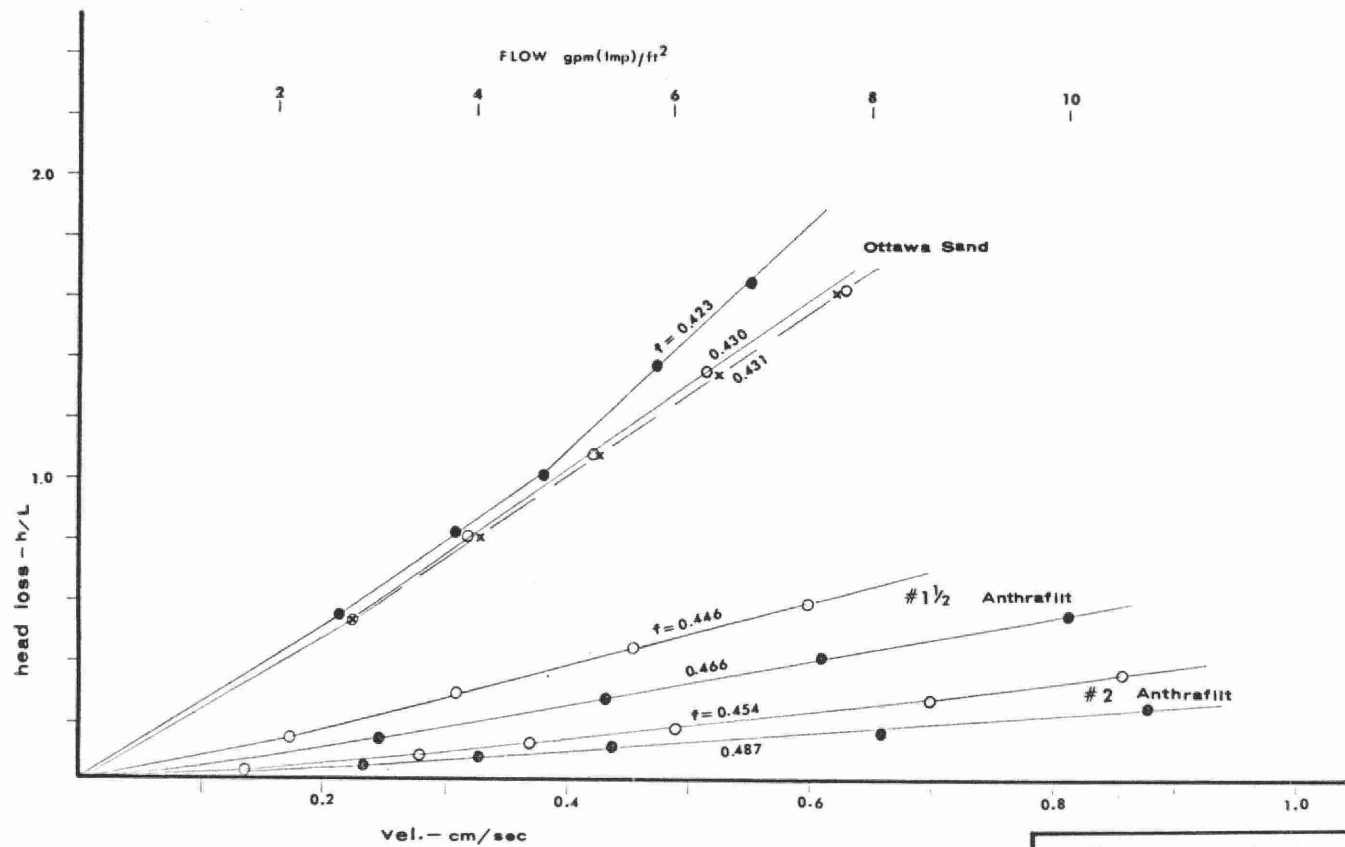
FLOW gpm(Imp)/ft^2

HEAD LOSS vs VELOCITY

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fig 3

CONCLUSION

The mean experimental data for each of the filter media are plotted in Figure 4, along with the theoretical values as computed from the formula: (1)

$$h/_L = 1.067 \; \frac{C_d}{g} \; \cdot \; \frac{1}{f^4} \; \cdot \; \frac{v^2}{d}$$

where $C_d = \dfrac{24}{R} + \dfrac{3}{\sqrt{R}} + 0.34$

$$R = \frac{vd}{\nu}$$

$h/_L$ = head loss per unit filter depth

f = porosity

v = flow rate, cm/sec

d = effective grain size

It will be noted that the experimental data are consistently below the theoretical values. This obtains in spite of plotting theoretical values for a media with sphericity (ψ) of 1, i.e.: for spheres.

If it is assumed that flow through a filter is laminar and that the porosity (f) will be approximately 0.4, a simplified calculation of head-loss is possible. These assumptions are generally valid as indicated by the porosity values obtained in the experimental runs, and by calculation of maximum values of Reynold's number (R), at

a velocity of 1.0 cm/sec, grain size of 0.1 cm, and kinematic viscosity of 1.3 centistokes (T=10°C). At this point R = 7.7 which is still within the range of laminar flow. (2)

With the assumption of laminar flow
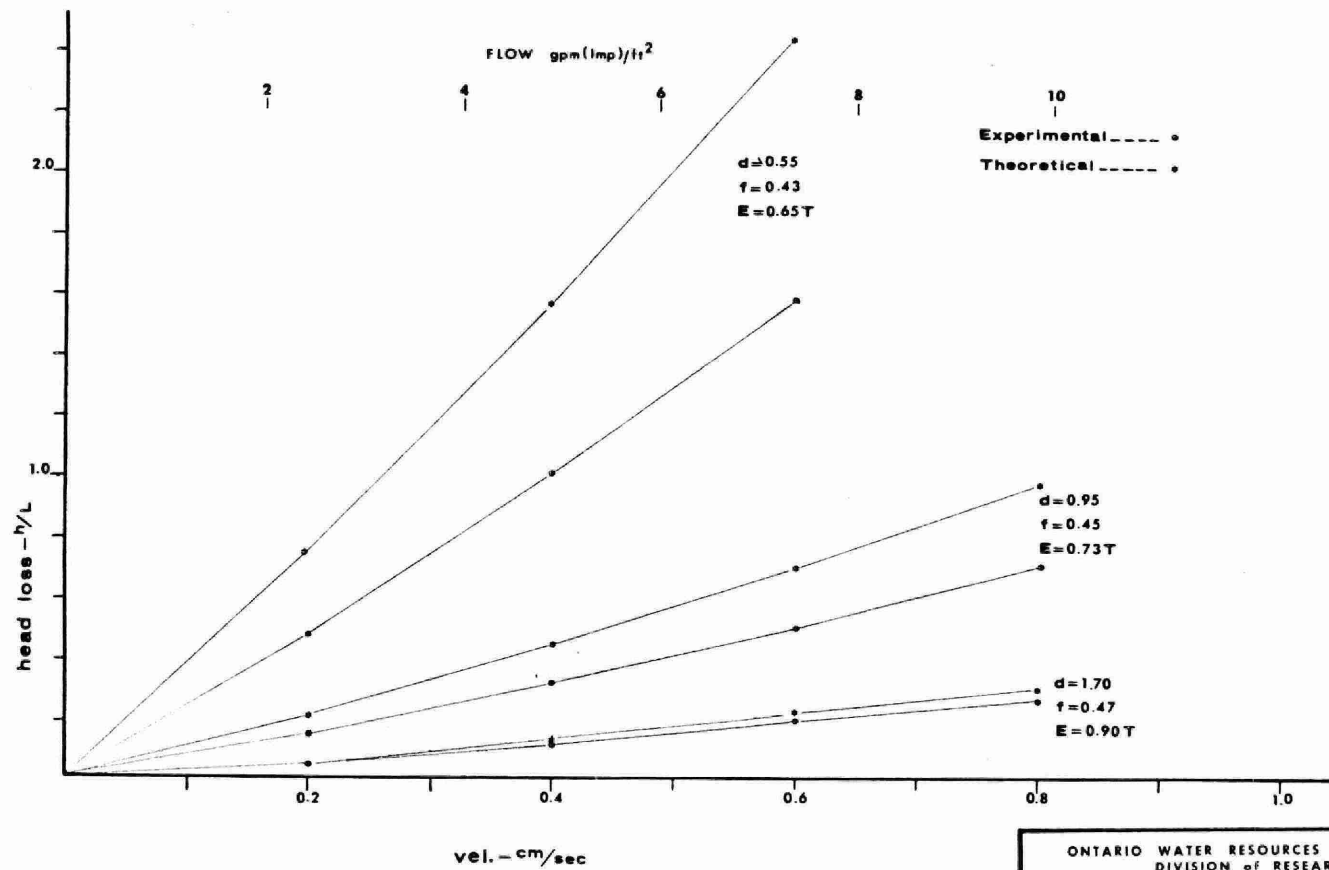
$$c_d = \frac{24}{R}$$

where $R = \frac{vd}{\nu}$

and $h/_L = 1.067 \frac{c_d}{g} \cdot \frac{1}{f^4} \cdot \frac{v^2}{d}$

$$= 25.6 \ \nu/g \cdot \frac{1}{f^4} \cdot \frac{v}{d^2}$$

and if f = 0.4

$h/_L = 1.02 \ \nu v/d^2$ (metric units)

As previously stated the experimental results obtained were consistently lower than the theoretical values calculated by the above methods. This would indicate that a calculation of initial head-loss based on either of these methods will produce a conservative design. If initial head-loss is a critical factor in the design it is recommended that a model study be carried out.

FLOW gpm(Imp)/ft²

2   4   6   8   10

Experimental ____ •
Theoretical _____ •

2.0 —

$d = 0.55$
$f = 0.43$
$E = 0.65 T$

1.0 —

$d = 0.95$
$f = 0.45$
$E = 0.73 T$

$d = 1.70$
$f = 0.47$
$E = 0.90 T$

head loss — h/L

0.2   0.4   0.6   0.8   1.0

vel. — cm/sec

$t = 10°C$

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EXPERIMENTAL vs. THEORETICAL

RESULTS

fig. 4

— 10 —

APPENDIX A

SAMPLE CALCULATIONS

Ottawa Sand

net weight of total sample (air dried) 9929.6 gms

voids:

dry wt.	1,000 gms
loose vol. of sand	620 cm^3
water added	500 cm^3
total vol.	1,120 cm^3
apparent vol.	880 cm^3
therefore: void vol.	240 cm^3

porosity:

$f = \dfrac{240}{620} = 0.387$

when volume = 620 ml/1,000 gms

f = 0.387 when total sample occupies
9.9296 x 620 = 6156.35 cm^3

Filter column = $\dfrac{\pi \times 10.76^2 \times 1}{4}$ = 90.9091cm^3/cm

sand depth = 73.5 cms (T101)

therefore vol. = 73.5 x 90.9091 = 6681.9 cm^3

$f = \dfrac{6681.9}{6156.4}$ x 0.387 = 0.420

APPENDIX B

The following graphs giving theoretical unit head-loss values for various effective diameter particles at various flow rates were prepared from computer results of the empirical formula:

$$h/_L = 1.067 \; \frac{C_d}{g} \; \cdot \; \frac{1}{f^4} \; \cdot \; \frac{v^2}{d}$$

in which $C_d = \dfrac{24}{R} + \dfrac{3}{\sqrt{R}} + 0.34$
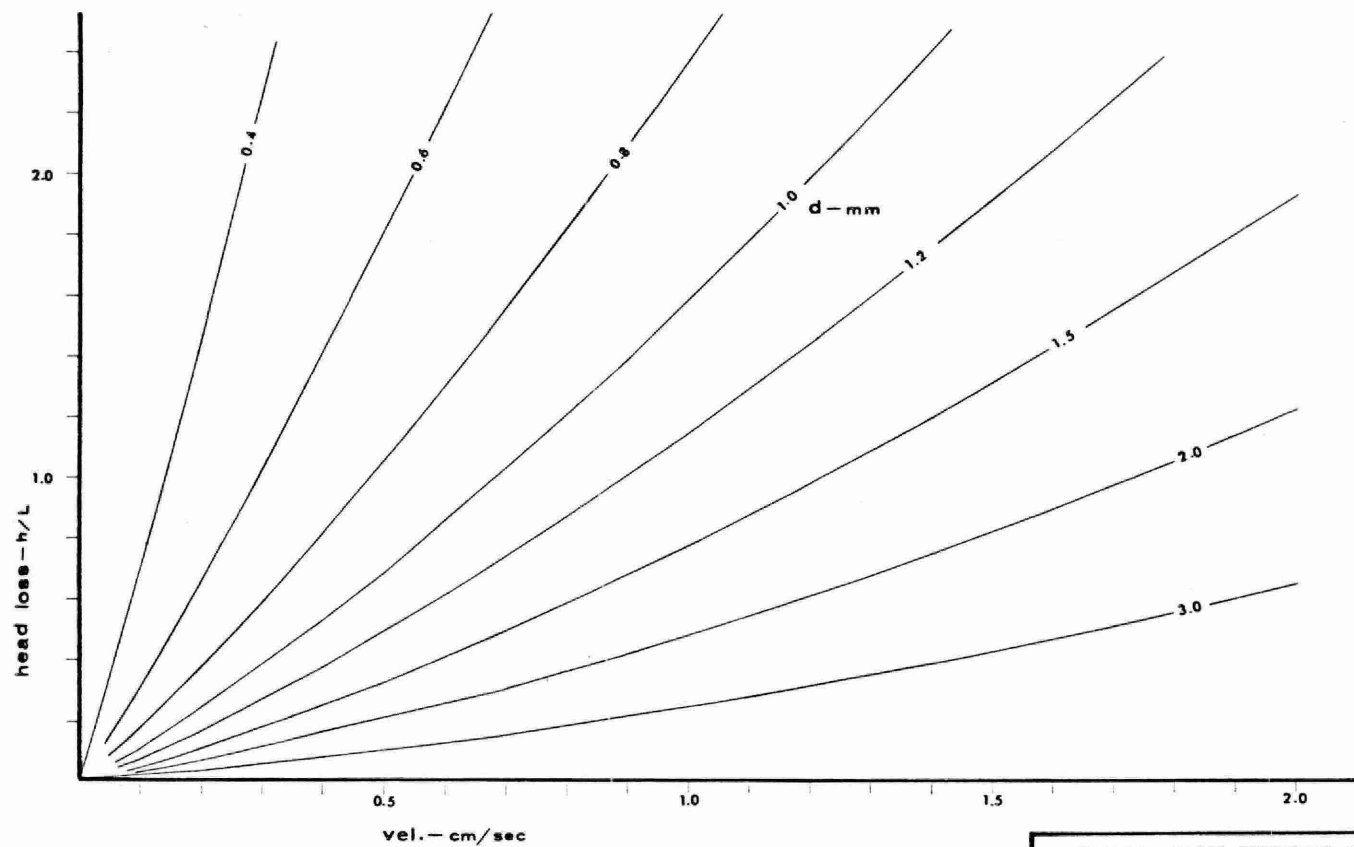
$g = 980.6 \text{ cm/sec/sec}$

$f = 0.400$

$v = \text{cm/sec}$

$d = \text{cm}$

TABLE B1

Porosity (f) Correction

f	Multiply $h/_L$ by	f	Multiply $h/_L$ by
0.30	3.160	0.45	0.624
0.31	2.783	0.46	0.571
0.32	2.440	0.47	0.525
0.33	2.159	0.48	0.482
0.34	1.916	0.49	0.444
0.35	1.707	0.50	0.410
0.36	1.524	0.51	0.378
0.37	1.366	0.52	0.350
0.38	1.228	0.53	0.324
0.39	1.107	0.54	0.301
0.40	1.000	0.55	0.280
0.41	0.906	0.56	0.260
0.42	0.823	0.57	0.242
0.43	0.749	0.58	0.226
0.44	0.683	0.59	0.211

head loss—h/L

vel.—cm/sec

d—mm

0.4 0.6 0.8 1.0 1.2 1.5 2.0 3.0

2.0

1.0

0.5 1.0 1.5 2.0
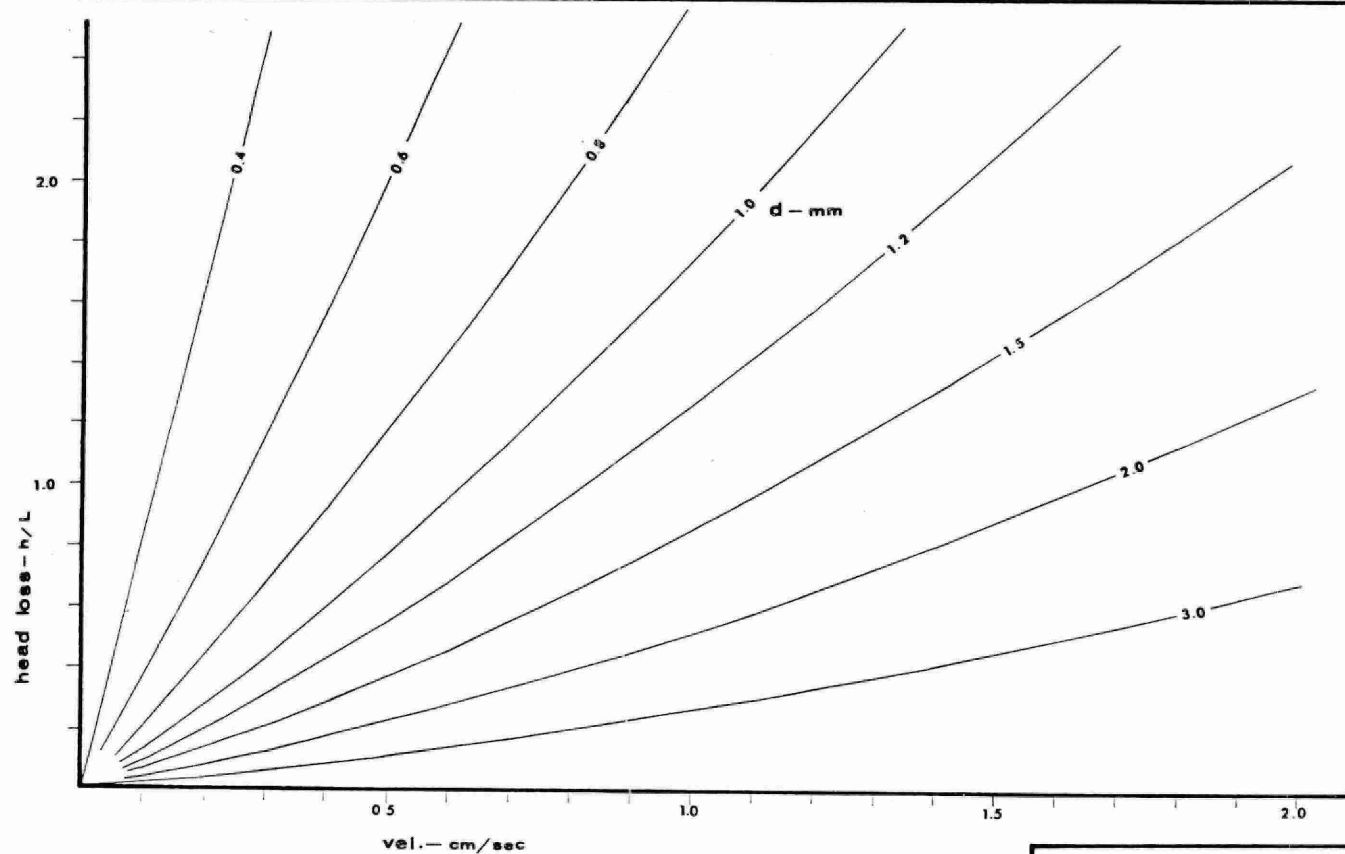
$t = 20^0 c$ $f = 0.40$

2 gpm (Imp)/ft^2 = 0.163 cm/sec

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HEAD LOSS vs VELOCITY

fig 5

head loss — h/L
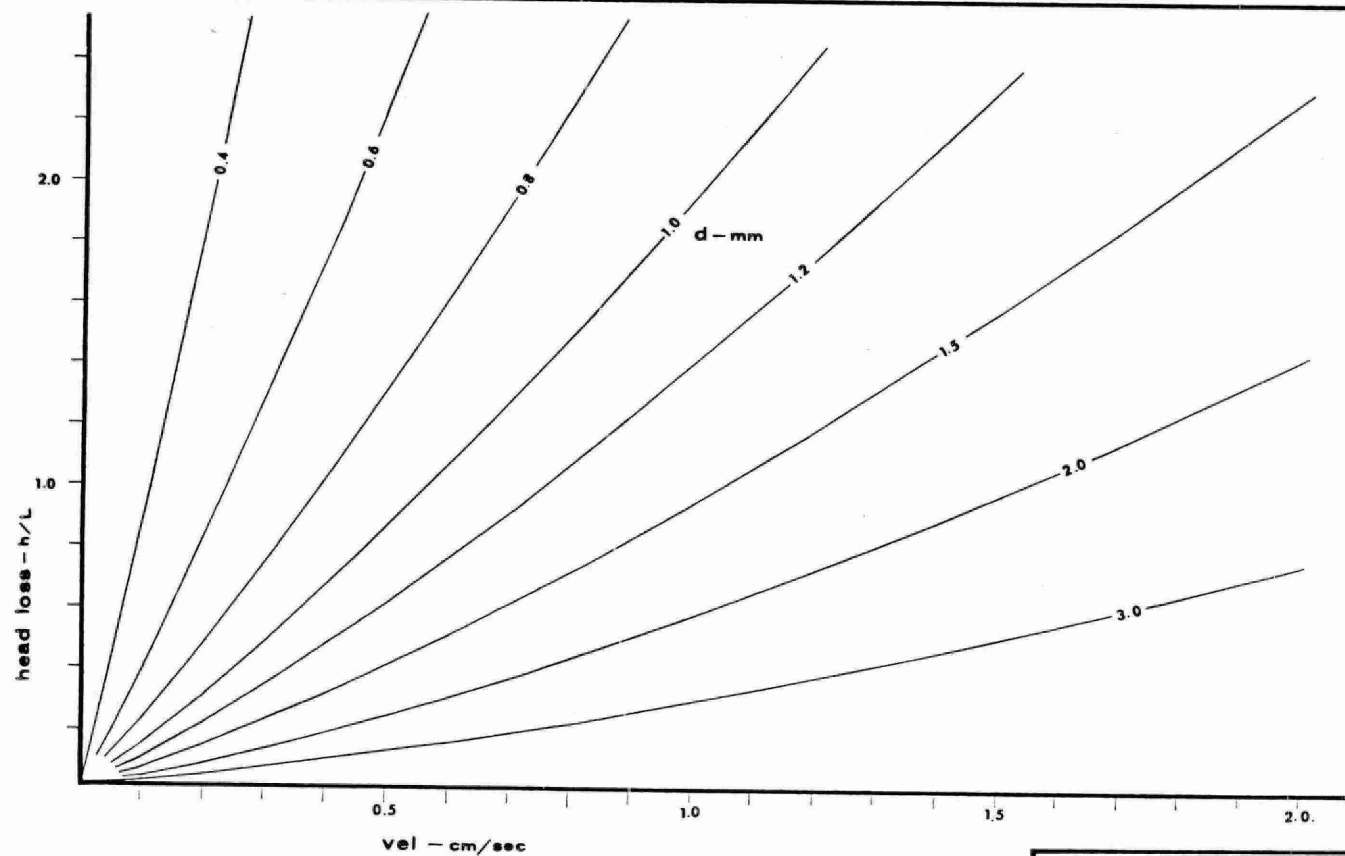
vel. — cm/sec

0.4
0.6
0.8
1.0 d — mm
1.2
1.5
2.0
3.0

2.0

1.0

0 5

1.0

1.5

2.0

$t = 15^0 c$ $f = 0.40$

2 gpm(imp)/ft^2 = 0.163 cm/sec

HEAD LOSS vs VELOCITY

fig 6

HEAD LOSS vs VELOCITY

head loss – h/L

vel – cm/sec

0.4   0.6   0.8   1.0   d – mm   1.2   1.5   2.0   3.0

2.0

1.0

0.5   1.0   1.5   2.0.
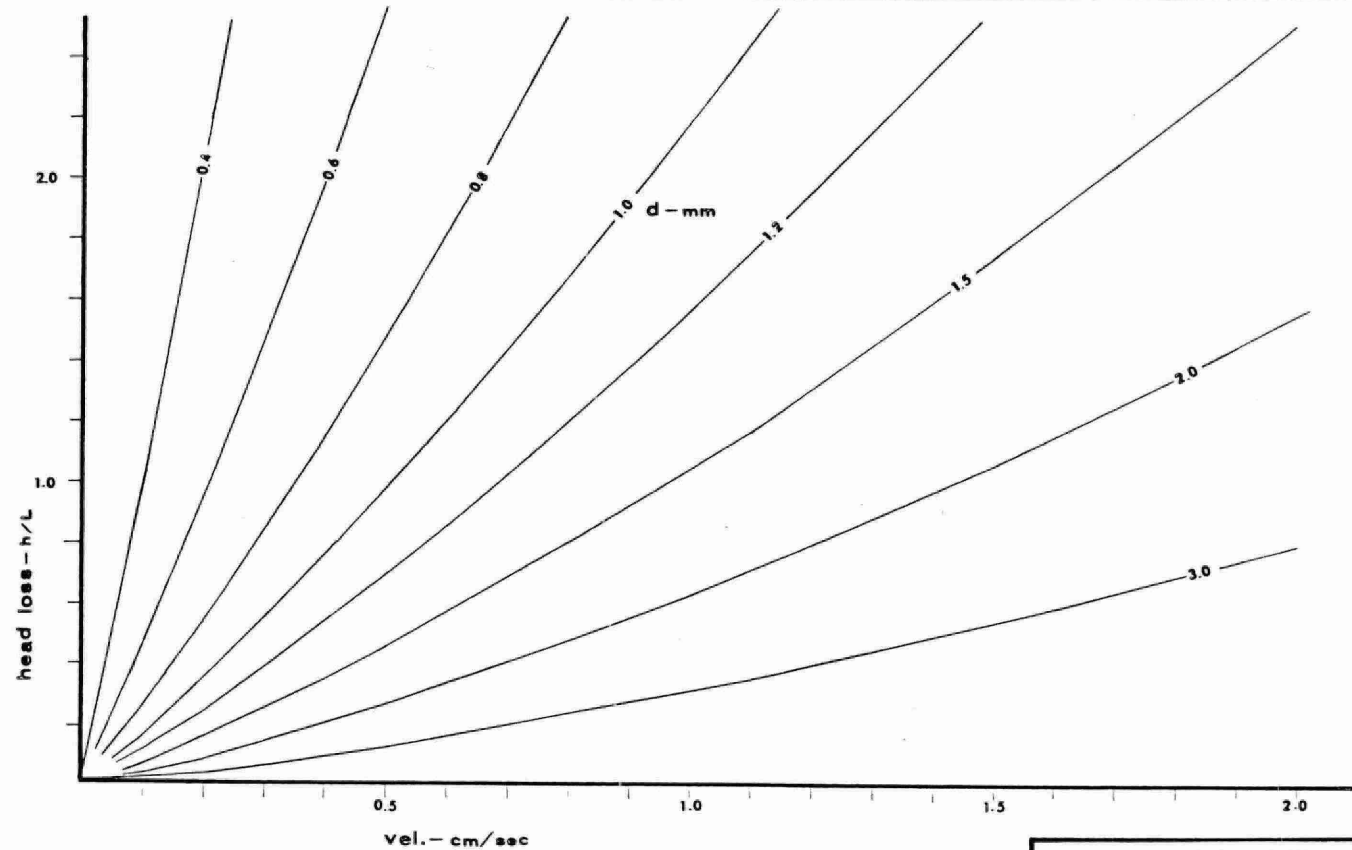
t = 10°c   f = 0.40

2 gpm (Imp)/ft² = 0.163 cm/sec

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HEAD LOSS vs VELOCITY

fig 7

head loss — h/L

vel. — cm/sec

2.0

1.0

0.5   1.0   1.5   2.0

0.4   0.6   0.8   1.0 d — mm   1.2   1.5   2.0   3.0

HEAD LOSS vs VELOCITY

$t = 5^0 c$ $f = 0.40$

$2 \, gpm \, (imp)/ft^2 = 0.163 \, cm/sec$

fig 8

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